Data Requirements and Preliminary Results of an Analog-Model Evaluation— Arkansas River Valley in Eastern Colorado[a]

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Abstract

The intensively irrigated Arkansas River Valley in Colorado is underlain by a valley-fill aquifer resting in a U-shaped trough cut in relatively impermeable Cretaceous rocks. Ground water is pumped to supplement surface water; in the last 10 years pumping has more than doubled. Ground water is closely related to the Arkansas River; percolation from irrigation recharges the aquifer, which discharges into the river. Pumping has resulted in a reduction in streamflow because it intercepts water that ordinarily would have reached the river. The 1,500 irrigation wells in the Arkansas Valley withdrew 230,000 acre-feet of water in 1964.

An analog model is being used to evaluate the relation of ground water to surface water and to predict effects of changes in water management. The model, simulating a 150-mile reach of the Arkansas Valley (Pueblo to the State line), has a resistor spacing of 8 per modeled mile. The framework for the model was a transmissibility map; transmissibility ranges from less than 50,000 to 700,000 gallons per day per foot. Specific yield averages about 0.2. Hydrologic boundaries, such as the Arkansas River, and the bedrock valley-fill contact were simulated. Applied water, precipitation, evapotranspiration, and ground-water pumping were the independent variables programed. The model is being verified by comparing predicted changes in water level and river discharge with observed changes.

Introduction

The Water Resources Division of the U. S. Geological Survey is making a study of the water resources of the Arkansas Valley, in cooperation with the Colorado Water Conservation Board and the Southeastern Colorado Water Conservancy District.

The reach being studied extends from Pueblo to the Kansas line, 150 miles (Figure 1). The patterned area on Figure 1 outlines the approximate extent of the valley-fill aquifer. The aquifer—consisting of sand, gravel, clay, and silt—ranges from 1 to 14 miles in width and averages 3 miles. The river is hydraulically connected with the aquifer, and ground water and surface water constitute a common supply. The usable ground water in storage is about 1 million acre-feet.

The irrigation economy of the Arkansas Valley was originally developed with surface water, but storage facilities are small and streamflow is irregular.

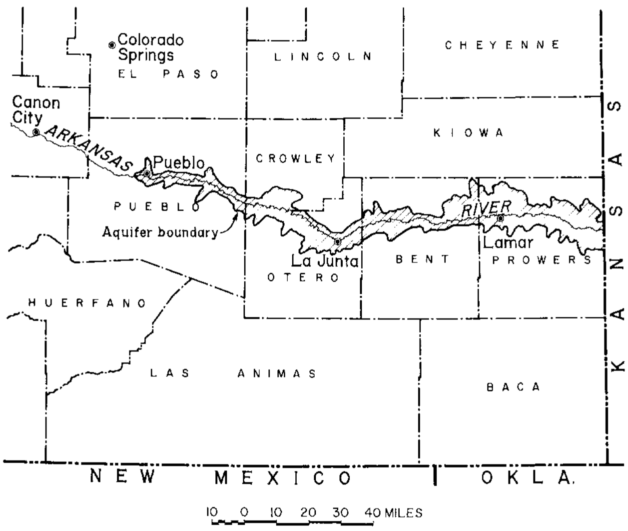

Fig. 1. Extent of valley-fill aquifer of Arkansas Valley in southeastern Colorado.

The amount of surface water available depends primarily on snowmelt in the Rocky Mountains, as the mean annual precipitation east of Pueblo is only about 12 inches. Irrigation water, therefore, is most plentiful from spring until early summer. The surface-water supply in middle and late summer, when crops are maturing and consumptive use is greatest, is often inadequate or lacking. The use of the ground-water reservoir alleviates this inadequacy, and many large-capacity wells have been installed in the Arkansas Valley to supplement the surface-water supply. About 1,500 large-capacity irrigation wells were pumped in the Arkansas Valley in 1964. Most of the wells have been drilled since World War II, and their number has more than doubled in the past 10 years. Withdrawal of ground water increased from 90,000 acre-feet in 1954 to 230,000 acre-feet in 1964.

Wells intercept some of the ground water moving toward the river as return flow. In many reaches of the stream, pumping of ground water reverses the slope of the water table, and water moves from the river toward the wells. Some reaches of the river that formerly were gaining are now losing. These losses decrease the amount of water in the river available for diversion. The unregulated use of ground water benefits those who have wells but works a hardship on those who have only surface-water rights. To minimize this adverse effect and to achieve the maximum use of the available water supply, ground water and surface water must be developed and managed as a unit.

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The purpose of this study is to evaluate the operation of the hydrologic system quantitatively so that effects of possible changes in water management can be predicted. To this end, an analog model of the valley was constructed. Because of the many unknowns, the large mass of data, and complex hydrologic interrelations, evaluations could not be made without such a model.

A 14-mile reach of the valley was selected as an example to illustrate the techniques used to build and evaluate the model.

Data Collection and Evaluation

The study was divided into two basic phases: (1) the definition of the physical limits and character of the ground-water reservoir; and (2) the relations of ground water, surface water, and climate.

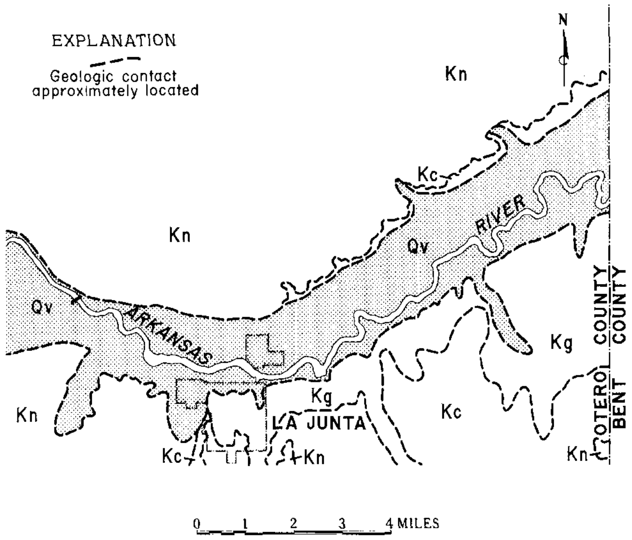

Fig. 2. Geologic map of a 14-mile reach of the Arkansas Valley. Geologic units (youngest to oldest) are: Qv, valley fill of Quaternary age; Kn, Niobrara Shale; Kc, Carlile Shale; Kg, Greenhorn Limestone, all of Cretaceous age.

On the geologic map (Figure 2) are shown the valley fill and bedrock. The valley fill, which is an aquifer, consists of gravel, sand, silt, and clay of Pleistocene to Recent age. The aquifer in this 14-mile reach averages 2 miles in width and rests in a U-shaped trough cut in bedrock. The bedrock, which acts as a barrier to ground-water movement, consists of shale and limestone of the Niobrara Shale, Carlile Shale, and Greenhorn Limestone, all of Late Cretaceous age. The geology of the Arkansas Valley is discussed more completely in reports by Voegeli and Hershey (1965) and Weist (1965).

The relation of valley fill to bedrock is shown on an idealized north-south section of the valley (Figure 3). The permeability of the valley fill is many times that of the bedrock, and, therefore, the bedrock acts as a barrier to the movement of water. Wells tapping the valley-fill aquifer yield as much as 3,000 gpm (gallons per minute); average yield is about 600 gpm.

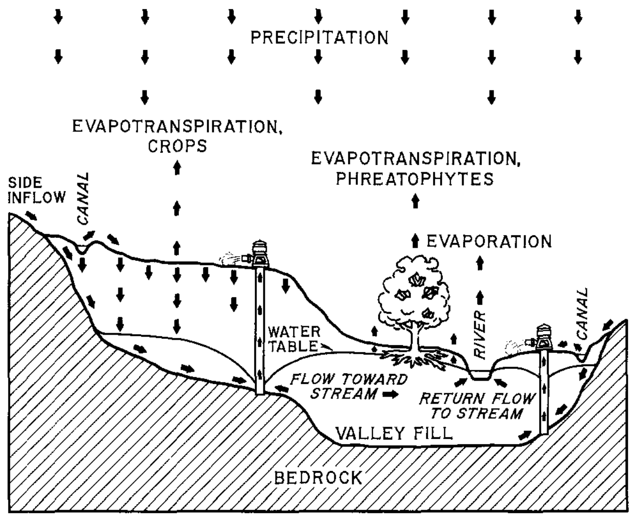

Fig. 3. Idealized north-south section of the Arkansas Valley, showing recharge, movement, and discharge of ground water.

Well data were collected to define the physical character of the aquifer. Where there were no wells or where data were lacking, test holes were augered. Observation wells were installed where additional water-table control was needed. Water-table, bedrock-contour, saturated-thickness, and depth-to-water maps were constructed from field data. In addition, pumping tests were made to determine transmissibility and specific yield.

In the second phase of the study, data on irrigation water, precipitation, evapotranspiration, and river gain and loss were collected. The river is hydraulically connected in varying degrees to the aquifer (Moore and Jenkins, 1966) and, during much of the year, drainage from the aquifer sustains the flow of the river (Figure 3).

The aquifer is recharged in large part by canal leakage and by downward percolation of surface water applied to crops (Figure 3). About 70 percent of diverted surface water is consumed (Moulder and others, 1963; Moulder and Jenkins, 1964). Precipitation also provides some recharge. Ground water that is not pumped, evaporated, or transpired seeps to the river. Evapotranspiration on the flood plain, where the water table is less than 10 feet from the surface, may be as much as 3 feet of water per year.

Eight water-level measurements of about 1,000 wells have been made since 1963, and water-level change maps have been constructed. An example of water-level changes between May and October 1964 is shown on Figure 4. Changes are shown by patterns. Declines were as great as 6 feet, and rises were less than 1 foot. Average decline was about 2 feet. The black dots on the map indicate irrigation or municipal wells. Areas of greatest decline correspond to areas of greatest withdrawal of ground water. The net loss from ground-water storage in the reach, as indicated by the change map, was about 5,000 acre-feet. About 21,000 acre-feet of ground water was pumped during

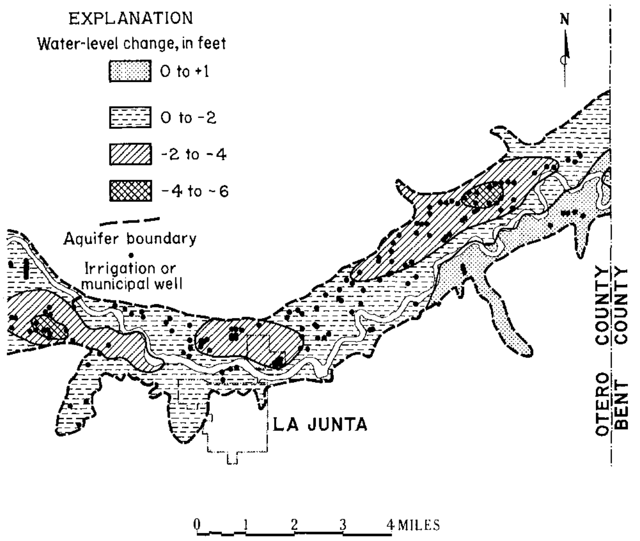

Fig. 4. Water-level change map (May to October 1964) of a 14-mile reach of the Arkansas Valley, as determined from field measurements.

this period. The difference (16,000 acre-feet) was derived from recharge, from applied water, and from the river. About 5,000 acre-feet of the pumpage was supplied from the river. The amount of river contribution was determined by comparing this change map with the May to August change map. There was no decline in ground-water storage from August to October. The channel-loss and channel-gain measurements indicate that during this period the river was probably losing water in an amount equal to the discharge of the wells.

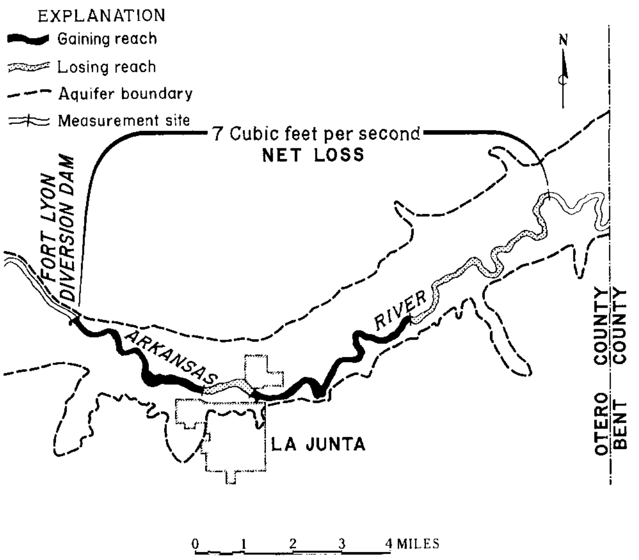

Fig. 5. Channel-gain and channel-loss measurements, May 15, 1964.

Results of two channel-gain and channel-loss studies are shown on Figures 5 and 6. On these maps gain is shown in black, and loss is shown by a stippled pattern. Points where measurements were made are shown by black lines. Inflow of surface water and diversions have been eliminated from the calculations, and only ground-water inflow to the river or loss from the river is represented. In May, before much ground-water pumping, the river between the Fort Lyon Diversion Dam (near La Junta) and a point near the county line had a net loss of 7 cfs (cubic feet per second) (Figure 5). In July, the period of greatest pumping, the river between the same points had a net loss of 37 cfs (Figure 6). The areas of greatest loss

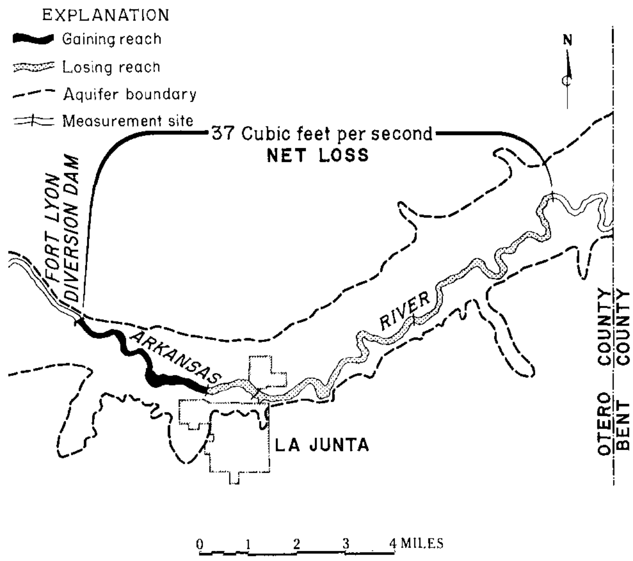

Fig. 6. Channel-gain and channel-loss measurements, July 17, 1964.

correspond closely to areas of greatest decline of water level and to areas of greatest withdrawal of ground water (Figure 4).

Construction of Analog Model

The basic framework on which the model was built – the transmissibility and boundaries of the hydrologic system (the Arkansas River, and the bedrock and valley-fill contact) – is shown on Figure 7 for the 14-mile reach. The transmissibility is estimated from pumping tests, well logs, saturated-thickness map, and water-table contour maps. In this part of the valley, transmissibility ranges from less than 50,000 to about 200,000 gallons per day per foot. The variation is caused by differences in saturated thickness or in permeability. The specific yield was determined from pumping tests and neutron-moisture data to be about 0.2.

The model, simulating the 150-mile reach of the Arkansas Valley (Pueblo, Colorado, to the Kansas line), is built on four connected panels and is 48 feet long and 6½ feet high. The model was constructed on a scale of 4 inches equal 1 mile, with a resistor at ½-inch intervals between junctions. The model contains about 100,000 resistors and 10,000 capacitors.

Calibration of Model

Independent variables of the hydrologic system such as recharge from applied water, precipitation, and evapotranspiration were programed in stages to determine the effect of each on the hydrologic system.

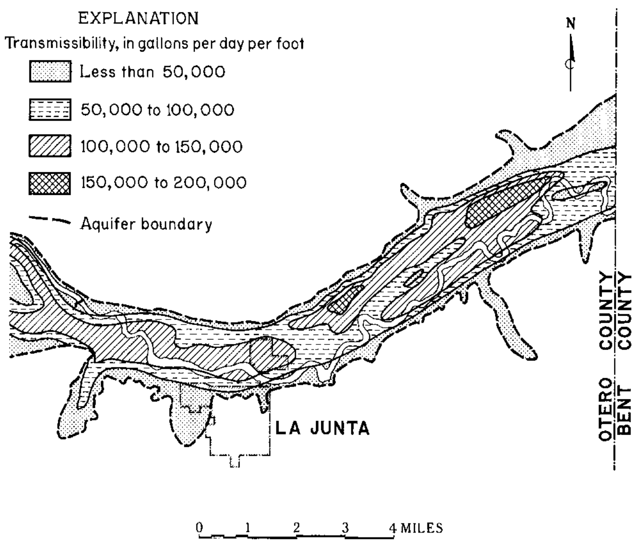

Fig. 7. Transmissibility map of a 14-mile reach of the Arkansas Valley.

For example, the first analysis of the model was made by simulating well pumping and observing water-level changes with no river recharge, precipitation, applied water, or evapotranspiration in the system. The maximum water-level decline was about 10 feet and the average decline in the 14-mile reach was 5 feet.

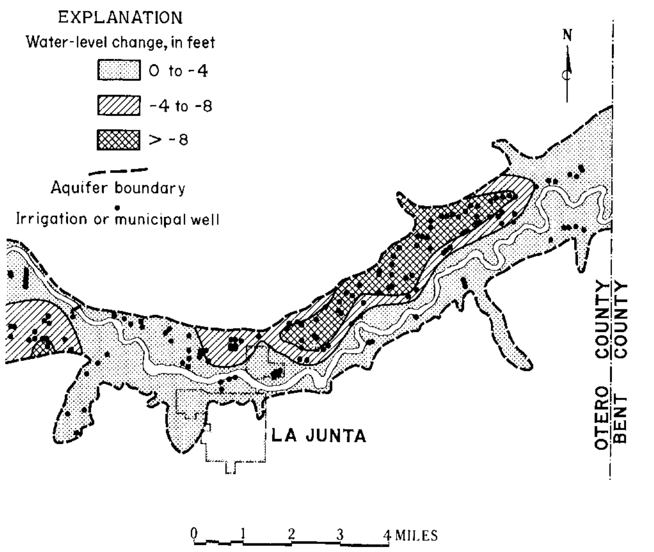

Fig. 8. Water-level change map (May to October 1964) as determined from analog model.

The next analysis of the model was made with the river added. The result of this analysis is shown on Figure 8. By adding the river the water-level changes were reduced, as would be expected, as the river and aquifer are hydraulically connected. The maximum water-level decline was about 8 feet and the average decline was 4 feet. The two analyses indicate that 26 acre-feet of water per day or an average of 13 cfs was withdrawn from the river or was intercepted return flow. This depletion of the river corresponds to the observed loss, which ranged from 7 to 37 cfs (Figures 5 and 6). The model analyses also indicate that 29 percent of the pumped water came from the river, or about 5,000 acre-feet from May to October. The river depletion predicted by the model is close to the depletion estimated by comparing field change maps and channel-gain and channel-loss measurements, as discussed earlier in this paper.

In general the analog analysis (Figure 8) compares closely with the field change map (Figure 4). The shape of the contours is similar to those constructed from field measurements, but the amount of change is greater. Much of the discrepancy between the maps can be explained by the fact that recharge from precipitation and applied surface water was not programed.

Use of Model

The analog model is now being tested at the Geological Survey's computer laboratory in Phoenix. The proper weighting of input factors to the model (such as recharge and evapotranspiration) will be determined by trial comparisons with observed aquifer response. The model will then be used to predict effects of changes in water management. Some evaluations that will be made by the model are as follows:

1. Quantitative evaluation of the effect of ground-water pumpage on seepage to and from the river.

2. Outline areas where ground-water supplies could be developed to satisfy senior water rights downstream from junior appropriators.

3. Provide a means of predicting water availability in different areas under different conditions of precipitation, surface-water delivery, and ground-water pumpage.

4. Define areas where additional ground-water withdrawal would be beneficial, such as salvage of ground water that is now being evaporated or transpired nonbeneficially.

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